APPLICATION FOR UNITED STATES LETTERS PATENT

FOR

METHOD OF USING HUE TO INTERPOLATE COLOR PIXEL SIGNALS

Inventor(s): Tinku Acharya
Ping-Sing Tsai

Prepared by: Howard Skaist,
Senior IP Attorney

intel®
Intel Corporation
2111 N. E. 25th Avenue; JF3-147
Hillsboro, OR 97124
Phone: (503) 264-0967
Facsimile: (503) 264-1729

"Express Mail" label number EL034434615US

METHOD OF USING HUE TO INTERPOLATE COLOR PIXEL SIGNALS

RELATED APPLICATION

This patent application is a continuation-in-part of US Patent Application Serial No. 09/410,800, titled "Method of Interpolation Color Pixel Signals from a Subsampled Color Image," by Acharya et al., filed on October 1, 1999, assigned to the assignee of the present invention

and herein incorporated by reference.

BACKGROUND

This disclosure is related to interpolating color pixel signal values for an image and, in particular, interpolating color pixel signal values using hue.

As is well-known, in a variety of circumstances, it is desirable to perform color interpolation. For example, for a camera or other imager that has the capability of creating a color image, typically it is too expensive to have the capability to capture three independent color pixel signal values for each pixel location of an image at least on part because this would employ additional sensors. Therefore, more typically, a subsampled color image is captured and then the missing color pixel signal values are computed using techniques of color interpolation. Most of the existing simple color interpolation techniques typically do not produce high-quality color images. Therefore, a need continues to exist for color interpolation

techniques capable of producing quality color images from a subsampled color image.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

FIG. 1 is a schematic diagram illustrating a subsampled color image, such as a Bayer pattern color mage;

FIG. 2 is a schematic diagram illustrating a portion of a subsampled color image in which the color pixel signal values are to be employed by an embodiment of a method in accordance with the present invention;

FIG. 3 is a schematic diagram illustrating a portion of another subsampled color image in which the color pixel signal values are to be employed by an embodiment of a method in accordance with the present invention;

FIG. 4 is a schematic diagram illustrating yet another portion of a subsampled color image in which the color pixel signal values are to be employed by an embodiment of a

method in accordance with the present invention.

DETAILED DESCRIPTION

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the present invention.

As previously indicated, in a variety of circumstances it may be desirable to have a capability to interpolate color pixel signals from a subsampled color image in order to recover the missing color components in a particular pixel location. FIG. 1 is a schematic diagram illustrating a Bayer pattern color image, which is one example of a subsampled color image, although the invention is not limited in scope in this respect. For example, many other well-known subsampled color images may be employed and will provide satisfactory results. As previously indicated, unfortunately, many color interpolation techniques typically do not produce high-quality color images at least in part because the techniques employed typically do not take into account, or at least reasonably correctly take into account, how the human eye perceives color. For example, a typical color interpolation technique may include averaging the pixels adjacent to a particular pixel location in which it is desired to interpolate the color signal value for those colors not included in that pixel location of a subsampled color image. However, typically, simply employing a pure average does not produce high quality results at least in part because it may blur the edge information and produce a color bleeding

problem, for example.

In this particular embodiment of a method of using hue to interpolate color pixel signals in accordance with the present invention, color interpolation is accomplished by comparing, for a particular pixel location in a subsampled color image, relative differences in hue for two mutually orthogonal directions across the particular pixel location. Hue, in this context, for red and blue, refers to the relative signal value of a blue or red signal value to a green signal value at a given pixel location. It is assumed that if a significant change in hue occurs in a particular direction, the color pixel signal values in that direction are not as representative of the color pixel signal values at the particular pixel location as are the color pixel signal values from the mutually orthogonal direction. For example, it may be that in the image, an edge is being encountered. Therefore, in computing the color signal value for that particular pixel location, the change in hue for a direction that indicates less change in hue is weighed more heavily, in this particular embodiment. It is believed that this is more representative of how the human eye perceives color because the human vision system is more responsive to the relative change of color in neighboring pixels than to the color information in the pixel itself. In addition, as explained in more detail hereinafter, in computing pixel signal values for particular colors, the change in hue from both directions are weighed, instead of only using the change in hue from one direction to the exclusion of the other direction.

FIG. 2 is schematic diagram illustrating a portion of a five pixel-by-five pixel grid of the Bayer pattern of FIG. 1. As illustrated, the center pixel location comprises a red pixel signal value. Therefore, for this particular pixel location, it is desired to interpolate the missing color signal values, blue and green, for that pixel location from the surrounding pixel signal values.

For example, a green pixel signal value may be estimated as follows. First, the relative change in hue for the horizontal direction and the vertical directions with respect to this particular pixel location, designated below as RCH_hor and RCH_ver, respectively, may be computed and compared. This is accomplished using the following equations.

$$\textbf{RCH\_hor} = \left| \tfrac{1}{2} \times [- R_{m,n-2} + 2\, G_{m,n-1} - 2\, G_{m,n+1} + R_{m,n+2}] \right|$$

$$\textbf{RCH\_ver} = \left| \tfrac{1}{2} \times [- R_{m-2,n} + 2\, G_{m-1,n} - 2\, G_{m+1,n} + R_{m+2,n}] \right| \qquad [1]$$

It is noted that for convenience, for the equations throughout the text of this specification, such as equations [1] above, it is assumed that the pixel signal values employed, such as $R_{i,j}$ or $G_{i,j}$, for example, are the logarithm of the pixel signal values having the corresponding designation from the subsampled image.

If the relative change in hue in the vertical direction is greater than the relative change in hue in the horizontal direction, then the values in the horizontal direction, that is, in this embodiment, the green and red pixel signal values that are the immediately adjacent pixel signal values in the horizontal direction, are weighed more heavily. In this embodiment, the weight assigned to these, 0.5 here, has been chosen based at least in part on fuzzy assignment concepts and experimentation, although the invention is not limited in scope in this respect. It is noted that other weights may be employed and provide satisfactory results. At the same time, the weights assigned to vertical signal values have been chosen as 0.1, although the invention is not limited in scope in this respect. On the basis of the above discussion, the missing green pixel signal values in this particular pixel location is estimated, in this embodiment, as

$$G_{m,n} = [\ 0.5 * (Ihor) + 0.1 * (Iver)\ ] / (0.5 + 0.1); \text{ or}$$

$$G_{m,n} = 2[0.41667 * (Ihor) + 0.08333 * (Iver)];$$

where [2]

$$Ihor = (G_{m-1,n} + G_{m+1,n})/2 + 0.5 \times (-R_{m-2,n} + 2\,R_{m,n} - R_{m+2,n})/4$$

$$Iver = (R_{m,n-1} + R_{m,n+1})/2 + 0.5 \times (-R_{m,n-2} + 2\,R_{m,n} - R_{m,n+2})/4$$

If the relative change in hue in the horizontal direction is greater than the relative change in hue in the vertical direction, then a reverse approach is employed. More particularly, the pixel signal signal values in the alternate directions, in this particular embodiment, are weighed more heavily. In particular, the green pixel signal value in this particular pixel signal location for such a situation is estimated as follows.

$$G_{m,n} = 2[0.08333 * (Ihor) + 0.41667 * (Iver)];$$

It is noted that the form of this equation is similar to the form above, except that the vertical and horizontal pixel signal values that were computed are interchanged. Finally, if the two relative changes are equal, or substantially equal, then a simple average of Iver and Ihor are employed in this embodiment.

$$G_{m,n} = 0.5 * (Ihor + Iver);$$

Therefore, in order to compute the signal value for the green color plane, where the particular pixel location has a pixel signal value in the red color plane, the relative change in hue in mutually orthogonal directions is compared. It is noted that where the particular pixel location has a blue pixel signal value in the Bayer pattern shown in FIG. 1, the structure of a five pixel-by-five pixel portion of the sub-sampled color image is similar in arrangement to that illustrated in FIG. 2, except the center pixel contains blue signal information instead of red signal information. Therefore, for a pixel location containing a blue signal value, in this embodiment, the missing green pixel signal value for that pixel location may be estimated by using a technique essentially the same as one previously described, replacing the red pixel signal value used in the equations above for a particular location with the blue pixel signal value for the particular location now being considered.

FIG. 3 is schematic diagram of another portion of the Bayer pattern of FIG. 1. This three pixel-by-three pixel portion is similar to a three-by-three portion of FIG. 2, except that pixel signal values in the respective corners of the three-by-three array have also been provided. For this portion, it is desirable to interpolate a blue pixel signal value for the location in which a red pixel signal value is provided. However, as illustrated in FIG. 3, blue pixel signal values immediately adjacent to the red pixel signal value are provided in the corners. Therefore, in contrast with the approach just described, the two mutually orthogonal directions to be compared comprise the main diagonal and the secondary diagonal of the array of pixels. Therefore, the relative change in hue across these two diagonals shall be compared. Hue, in this context, for red and blue, refers to the relative signal value of a blue or red signal value to a green signal value at a given pixel location. As previously indicated, the reason this approach is employed is because it is believed that hue information more

accurately reflects how the human eye perceives changes in color. Furthermore, a comparison for red and blue pixel signal values is made with green pixel signal values because, in Red-Green-Blue (RGB) color space format, the green plane includes a relatively larger amount of luminosity signal information compared to the red and blue planes. Hue for red or blue signal values, therefore, is estimated by comparison with the green value. Therefore, hue for the four blue pixel signal values is computed by comparing the blue pixel signal value in that location with the green pixel signal value in that location. It should be noted that the missing green pixel value has already been or may be recovered via the previous technique. Therefore, the following equations apply.

$$\begin{aligned} hue\_nw &= B_{m-1,n-1} - G_{m-1,n-1}; \\ hue\_sw &= B_{m+1,n-1} - G_{m+1,n-1}; \\ hue\_ne &= B_{m-1,n+1} - G_{m-1,n+1}; \\ hue\_se &= B_{m+1,n+1} - G_{m+1,n+1}; \end{aligned} \tag{3}$$

Then, the related change in hue along the main diagonal and the secondary diagonal may be computed as follows.

$$\begin{aligned} hue\_md &= | hue\_nw - hue\_se |; \\ hue\_sd &= | hue\_ne - hue\_sw |; \end{aligned} \tag{4}$$

As discussed above, if the hue in any particular direction changes more significantly, then the hue in the mutually orthogonal direction is employed to estimate the blue pixel signal value in a particular pixel location. More accurately, that direction in which there is less relative change in hue is weighed more heavily than in the direction in which the relative change in hue is greater. Employing the relative change in hue in this fashion, the blue pixel signal value may be estimated as follows, assuming the relative relative change in hue along the main diagonal is less.

$$B_{m,n} = (G_{m,n}) + 0.41667 * ((B_{m-1,n-1} - G_{m-1,n-1}) + (B_{m+1,n+1} - G_{m+1,n+1})) + 0.08333 * ((B_{m-1,n+1} - G_{m-1,n+1}) + (B_{m+1,n-1} - G_{m+1,n-1})); \quad [5]$$

Likewise, a similar equation is employed for the opposing diagonal, except that the signal values along the diagonals are interchanged, providing the following equation.

$$(B_{m,n}) = (G_{m,n}) + 0.08333 * ((B_{m-1,n-1} - G_{m-1,n-1}) + (B_{m+1,n+1} - G_{m+1,n+1})) + 0.41667 * ((B_{m-1,n+1} - G_{m-1,n+1}) + (B_{m+1,n-1} - G_{m+1,n-1})) \quad [6]$$

It is noted that interpolation of a red pixel signal value for a particular pixel location having a blue pixel signal value may be obtained using a similar approach except that in the above equation the blue pixel signal values are interchanged with red pixel signal values. This is because, as illustrated in FIG. 1, where the particular pixel location has a blue pixel

signal value, the pixel signal values in the four corners are red pixel signal values, providing substantially the same structure or array layout as illustrated in FIG. 3. Finally, a blue pixel signal value may be interpolated where a green pixel signal value is provided in the particular pixel location of the subsampled image, as illustrated in FIG. 4, for example. The approach is similar to that described in connection to the approach described with FIG. 3, except that, instead of employing the pixel signal values along the diagonals, the horizontal and vertical pixel signal values are employed using either horizontal or vertical pixel signal value directly available from the subsampled color image. The other pixel value in the orthogonal direction which is used for interpolation is obtained by employing the previous calculation. For example, the blue pixel signal values in the horizontal locations immediately adjacent the green pixel signal values in FIG. 4 are interpolated using the approach just described above in connection with FIG. 3. Therefore, the following equations are employed.

$$hue\_n = B_{m-1,n} - G_{m-1,n};$$

$$hue\_e = B_{m,n+1} - G_{m,n+1};$$

[7]

$$hue\_w = B_{m,n-1} - G_{m,n-1};$$

$$hue\_s = B_{m+1,n} - G_{m+1,n};$$

$$hhor = hue\_e - hue\_w;$$

$$hver = hue\_n - hue\_s,$$

where $B_{m,n+1}$ and $B_{m,n-1}$ are obtained from the previous interpolation calculation.

if (| hhor| < |hver|) ***then***

$$(B_{m,n}) = (G_{m,n}) + 0.41667 * ((B_{m,n-1} - G_{m,n-1}) + (B_{m,n+1} - G_{m,n+1})) +$$

$0.08333 * ((B_{m-1,n} - G_{m-1,n}) + (B_{m+1,n} - G_{m+1,n}))$.

else

$(B_{m,n}) = (G_{m,n}) + 0.08333 * ((B_{m,n-1} - G_{m,n-1}) + (B_{m,n+1} - G_{m,n+1})) +$

$0.41667 * ((B_{m-1,n} - G_{m-1,n}) + (B_{m+1,n} - G_{m+1,n}))$

endif

A similar approach may be employed to interpolate the red pixel signal value where the particular pixel location of the subsampled image includes a green pixel signal value, except that in the equations provided above, the blue pixel signal values are replaced by red pixel signal values, as follows

hue_n = $R_{m-1,n} - G_{m-1,n}$;

hue_e = $R_{m,n+1} - G_{m,n+1}$;

hue_w = $R_{m,n-1} - G_{m,n-1}$;

[8]

hue_s = $R_{m+1,n} - G_{m+1,n}$;

hhor = hue_e - hue_w ;

hver = hue_n - hue_s,

where $R_{m-1,n}$ and $R_{m+1,n}$ (or $R_{m,n-1}$ and $R_{m,n+1}$ depending on whether the particular pixel is located in the red-green row or blue-green row) are obtained from the previous interpolation calculation.

if (| hhor| < |hver|) ***then***

$$(R_{m,n}) = (G_{m,n}) + 0.41667 * ((R_{m,n-1} - G_{m,n-1}) + (R_{m,n+1} - G_{m,n+1})) + 0.08333 * ((R_{m-1,n} - G_{m-1,n}) + (R_{m+1,n} - G_{m+1,n})).$$

else

$$(R_{m,n}) = (G_{m,n}) + 0.08333 * ((R_{m,n-1} - G_{m,n-1}) + (R_{m,n+1} - G_{m,n+1})) + 0.41667 * ((R_{m-1,n} - G_{m-1,n}) + (R_{m+1,n} - G_{m+1,n}))$$

endif

It will, of course, be appreciated that the invention is not restricted in scope to a particular embodiment or implementation. For example, the foregoing approach, as one example of an approach in accordance with the invention, may be implemented in hardware, in software, in firmware, and/or any combination thereof. Again, intended merely as examples that do not limit the scope of the invention, an embodiment may comprise an imager including hardware, such as integrated circuit chips, that implement the foregoing. Alternatively, the imager may be coupled to a computing platform that includes software capable of implementing the foregoing. Likewise, a digital camera coupled to a desktop personal computer, for example, may implement an embodiment. Furthermore, these implementations in hardware and software may, of course, deviate from the foregoing and still be within the scope of the present invention.

For embodiments that are at least partially implemented in software, such as, for example, the previously described embodiment, such software may reside on a storage medium, such as, for example, random access memory, a CD ROM, a floppy disk, or a hard drive, such that instructions are stored, which, when executed, such as by a computing

platform, such as a PC or other computing device, so that the system is capable of executing the instructions to result in the interpolation of color pixel signal values from a subsampled image. Likewise, such software may reside in firmware also, such as in flash memory or EEPROM, for example.

While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes and equivalents will now occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.